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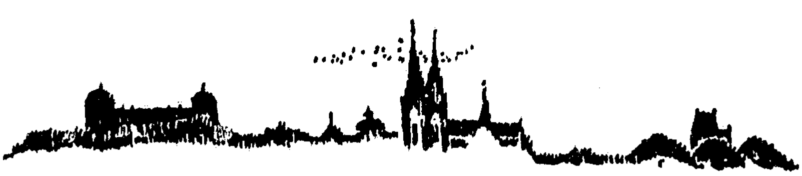

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Abstract

We report here the measurement of electrostatic and obviously locally produced noise near the lower hybrid frequency made by the sounding rocket S29 Barium-GEOS. The noise is strongly related to the spin of the rocket and reaches well below the local lower hybrid resonance frequency. Above the altitude of 300 km the noise shows banded structure roughly organized by the hydrogen cyclotron frequency. Simultaneously with the banded structure a signal near the hydrogen cyclotron frequency is detected. This signal is also spin related. The characteristics of the noise suggest that it is locally generated by the rocket payload disturbing the plasma. If this interpretation is correct we expect plasma wave experiments on other spacecrafts, e.g., the space shuttle to observe similar phenomena.

1. Introduction

Waves or noise near the lower hybrid resonance (LHR) frequency is a rather common phenomenon in the ionosphere and the magnetosphere. It has been measured in the distant magnetotail (e.g., IMP-8; Gurnett et al.,1976) on the magnetopause (e.g., ISEE-1 and ISEE-2; Gurnett et al.,1979), on the auroral field lines at high altitudes (e.g., IMP-6 and Hawkeye; Gurnett and Frank, 1977), and also lower in the ionosphere (e.g., satellites Alouette, OGO-4, Injun-5; Brice and Smith, 1965, Laaspere and Taylor, 1970). At the moment there are not so many reports of LHR noise from rocket flights, although we suspect that it could be seen (perhaps always) when measuring the electric wave fields in a proper frequency and altitude region within the auroral zone. The data presented here were recorded by the Swedish S29 Ba-GEOS rocket in September -79. Similar observations have been reported by Kamada et al. (1981) from the Japanese S-310JA-6 rocket. Recently, the Siple rockets (18.203, 18.204, and 18.205) and the Eclipse rocket (33.004) have observed similar spectral features near the LHR frequency (R. Pfaff and R. Brittain, private communications).

Waves somewhat above the LHR frequency are often identified as electromagnetic phenomena like auroral hiss, VLF-saucers etc., especially within satellite measurements. However, it does not seem to be possible to interpret all the measurements in this way; one reason is that the noise is not always cut off at the LHR frequency but reaches well below it while the electromagnetic resonance only occurs above the LHR frequency. There have not been many attempts to explain this theoretically, one of the few is discussed by Hamelin and Beghin (1976). Their curiosity arose from the previously mentioned "erroneous" cut-off and a harmonic ray structure seen in the measurements

made by rocket experiments Electron Echo 1 and CISASPE and by the satellite ISIS-2. They compared cold, warm and hot plasma theories in multicomponent plasma and their conclusion was that it should be possible to understand these phenomena with the aid of the hot theory. They suggest that emissions should occur near the LHR frequency accompanied by harmonic structure due to the Bernstein modes of the lightest ion constituent of the plasma. Their analysis is not complete, however, because they do not specify any source of free energy for the waves and only consider the so called excitation levels which effectively means to calculate the damping coefficient associated with each normal mode.

The possibility of exciting ion cyclotron harmonic waves by a rotating ion beam was investigated by Böhmer (1976). He showed that the perpendicular energy of the beam can be an effective source of free energy for the waves.

Recently, Cattell and Hudson (1982), and Kintner and Kelley (1982) have analyzed similar phenomena. Cattell and Hudson based their work on S3-3 satellite observations of conical ion distributions. They solved the linear dispersion relation numerically using a subtracted Maxwellian distribution, a warm ring in velocity space, as a distribution function of the warm ion beam. Their analysis showed that the observed ion beams can be unstable to lower hybrid emissions and the difference in perpendicular velocity between the beam and the background plasma could be the free energy source for the instability. Kintner and Kelley analyzed data from the Porcupine rocket. After a Xenon ion gun was used ion Bernstein modes were detected at least up to the tenth hydrogen cyclotron harmonic but the first two or three of them were missing. Kintner and Kelley solved the linear dispersion relation for the flute modes ($k_{\uparrow\uparrow}=0$) in an O^+ plasma with a small H^+ component and demonstrated that the absence of

the lowest order harmonics was possibly due to the oxygen cyclotron damping. The free energy source in their calculations was the perpendicular Xe^+ beam.

The work by Hamelin and Beghin reveals the possible electrostatic character of the noise near the LHR frequency which we believe to be important in interpreting electrostatic density fluctuations measured onboard the Ba-GEOS sounding rocket. In this report we shortly describe the measurement and present the most interesting data. A complete understanding of the LHR noise including the identification of the generation mechanism is yet to be achieved. It is the goal of this paper to describe the observed electrostatic emissions which suggest a local excitation source, possibly caused by the rocket payload disturbing the plasma, and to consider different sources of free energy.

2. The measurement

The principal objective of the S29 Barium-GEOS sounding rocket experiment was to inject a Barium ion jet in the ionosphere at 400 km altitude upward along the geomagnetic field lines which could be detected and analyzed by the geostationary satellite GEOS located at the equatorial plane. However, the observations that we are reporting and discussing here are not related to the Barium ion jet experiment. The data was collected by experiments on a separate payload and include both periods before and after the Barium ion jet injection.

The rocket was launched 24. September 1979 at 20.20:10 UT from Esrange (67.88 N; 21.07 E). It reached an apogee of 396.1 km and the range to impact was 62.4 km. The rocket motor configuration was Nike Black Brant VC.

The launch took place at the onset of a magnetic substorm, and the rocket passed quite close to and south of a westward travelling surge associated with the break up of an auroral arc that had become visible just a few minutes before launch (Opgenoorth et al., 1982). The payload penetrated active aurorae during the first part of the flight, while the activity, as shown by the electron and proton flux and the optical observations, decreased shortly before the Barium release at the apogee.

The payload was equipped with instruments for measurements of

- three electric wave components (E_x, E_y, E_z)
- two magnetic wave components (B_y, B_z)
- the (scalar) plasma density fluctuations ($\delta n/n$)

In addition to the plasma wave instruments, the quasi-dc electric field and the energetic electrons and ions were measured. The plasma density and electron temperature was measured by sweeping the potential of a $\delta n/n$-probe at 10 seconds intervals.

In this report, we refer primarily to the $\delta n/n$-instrument. The instrument consists of a small spherical probe mounted on a 50 cm long boom perpendicular to the rocket symmetry axis. Most of the time the probe was operated at a potential well above the plasma potential, a region where the probe current is only weakly dependent on changes in potential and directly proportional to the plasma density. Small fluctuations in probe current are thus interpreted as plasma density fluctuations. The instrument is sensitive to relative plasma density fluctuations ($\delta n/n$) in the approximate range 0.001 to 0.5, and in the frequency range up to 20 kHz. At regular intervals (about 10 seconds) the probe potential is swept around the plasma

potential, thus yielding a measurement of the absolute electron density and temperature.

The electric wave components were measured by the double probe technique, with a probe separation of 4.2 meters. Electrical contact with the plasma was made with aquadag coated spheres and the potential of each sphere was measured with a high input impedance preamplifier. The differential potential was amplified by a digital automatic gain control and then transmitted to the ground over the frequency range 30 Hz to 16 kHz.

3. Data

In figure 1 the spectrogram of the $\delta n/n$ measurement is represented together with a theoretical estimate of the LHR frequency

$$f_{LHR} = \left(\frac{1}{f_{ce}^{2}} + \frac{1}{f_{pe}^{2}}\right)^{-\frac{1}{2}} \left(\frac{\overline{f}_{ci}}{f_{ce}}\right)^{\frac{1}{2}}$$

where f_{ce} is the electron gyrofrequency, f_{pe} the electron plasmafrequency and the effective ion gyrofrequency $\overline{f_{ci}}$ is

$$\overline{f}_{ci} = eB \sum_{j} \frac{X_j}{m_j}$$

where j runs over the ion species and X_j is the percentage of ions of the j'th species. Note that the vertical lines in the figure are wideband noise caused by the periodic potential sweeps, about once every ten seconds.

The LHR noise becomes visible in the $\delta n/n$ data at about 114 seconds after launch and is in the beginning quite diffuse. After 144 sec. there appear two frequency bands with a clear low-frequency cut-off at about 4.4 kHz. The lower band is centered at 5 kHz and above it there is a less noisy region. The upper band begins below 7 kHz and reaches up to 12.5 kHz (or higher) which is the upper

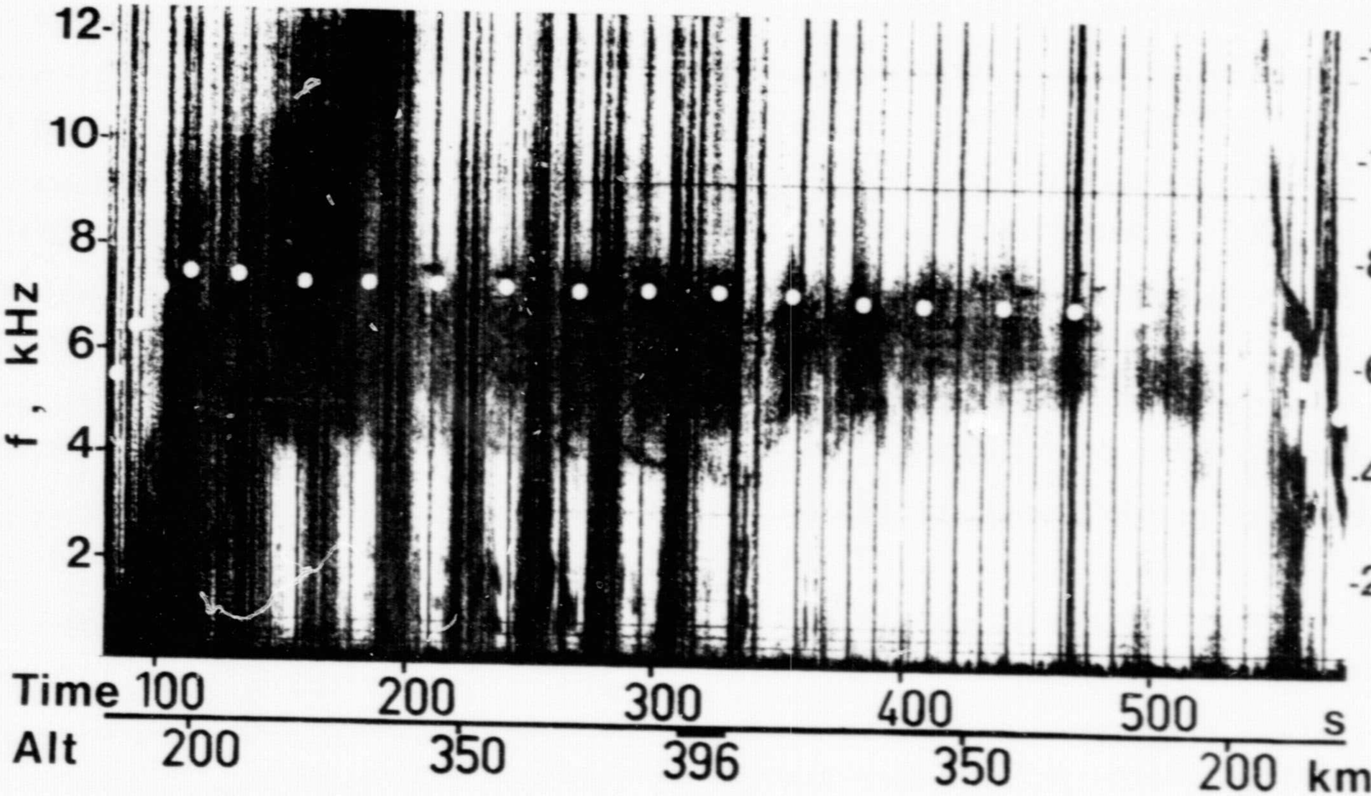

Figure 1

Sonogram of $\delta n/n$ data as a function of flight time and altitude. The white dots denote the local LHR frequency calculated from the measured plasma density, the magnetic field model IGRF 75 and a typical ion composition.

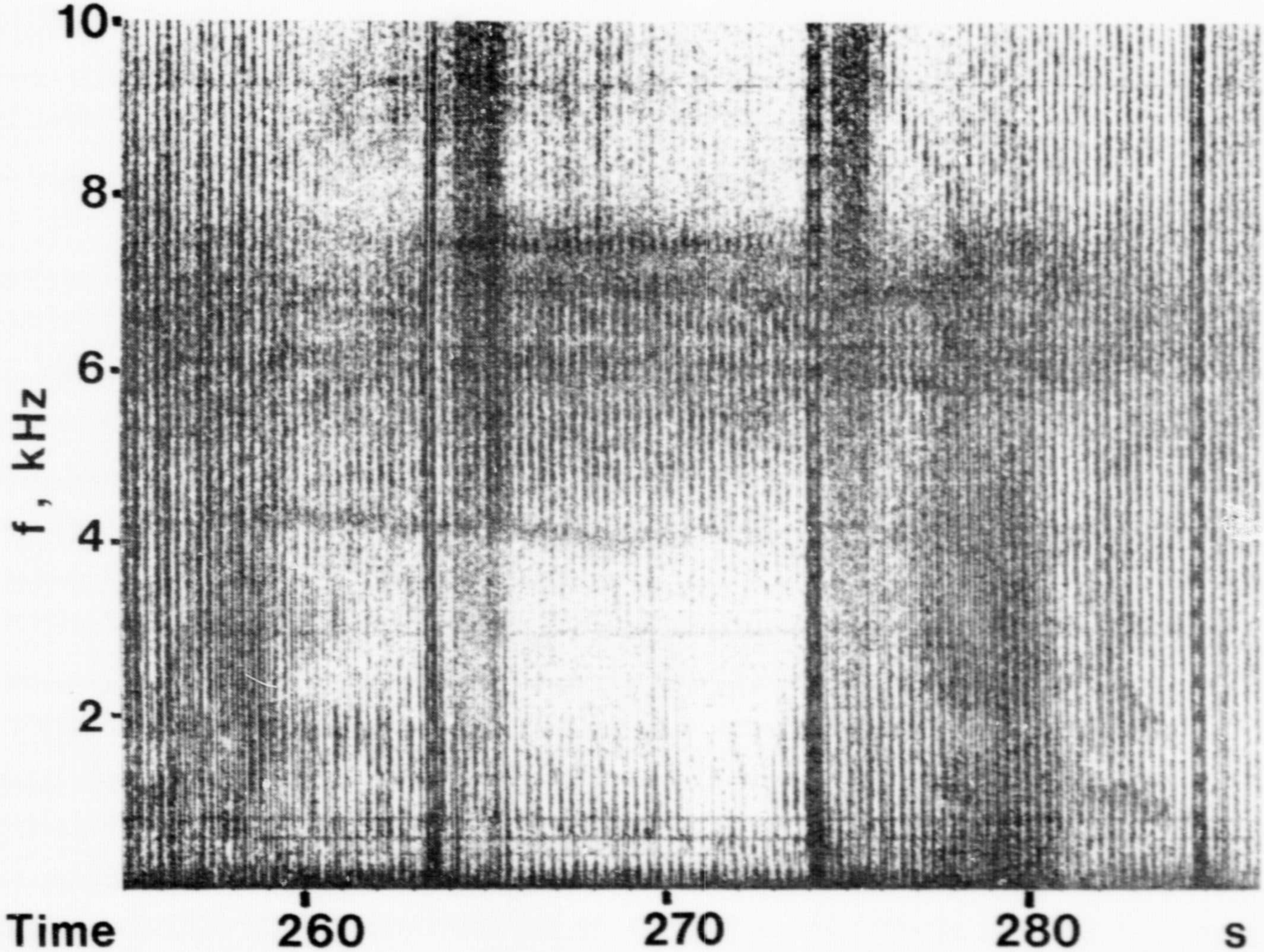

Figure 2

Sonogram showing the typical features of the banded structures.

limit of our analysis. The electric field data from the same time period is very similar though these bands can be seen already somewhat earlier in time. However, in the electric field data the "higher" band is quite narrow and there is a less noisy region above it. At the frequencies above the LHR frequency (≃7.3 kHz) there is additional broad band noise.

At 180 sec. (at a height of 300 km) this noise changes its character. The noise level becomes lower and there is not much noise above, say, 7.5 kHz. Now there seems to be some band structure in the noise (fig.2). Sometimes it is quite stationary, sometimes variable and it is also spin correlated. The interesting point here is that on the average these bands are separated by the hydrogen cyclotron frequency (680 Hz). Figure 3 is another representation of one part of figure 2 where these features are seen more in detail. In that figure a signal just above the fundamental hydrogen cyclotron frequency can also be seen.

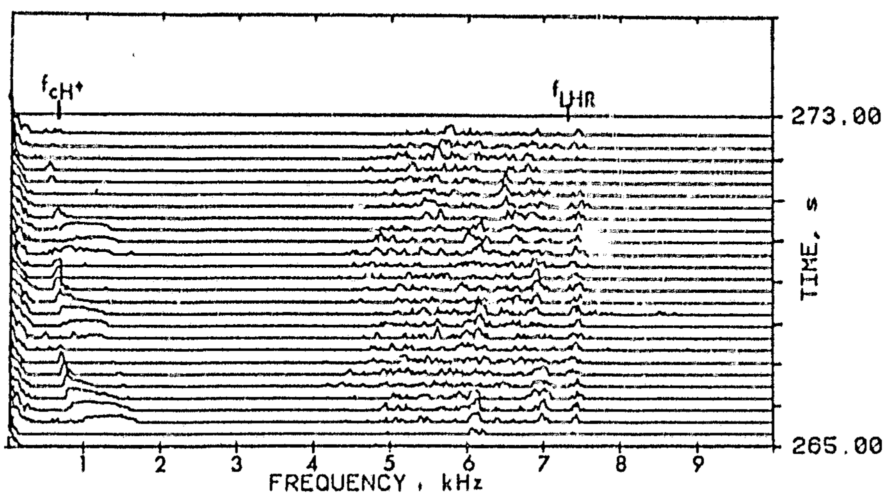

Figure 3. Banded structures and the signal near the hydrogen cyclotron frequency. Each spectrum is an average over one spin period (5 individual spectra).

Figure 4 represents a shorter interval of the data with a better temporal resolution. Here we can see that the highest frequency part of the LHR noise which is somewhat above the LHR frequency occurs in the same spin phase of the rocket as the signal near the hydrogen cyclotron frequency. This feature corresponds to about 70 degrees of the revolution of the rocket around its spin axis. During this period the signal near the ion cyclotron frequency is shifted upwards in the frequency. This shift is often so large that it seems to be very difficult to explain it as a consequence of Doppler shifting. After this period the other LHR noise bands follow after each other. The occurences of the highest of the noise bands and the possible electrostatic ion cyclotron (EIC) waves coincide well with the time that the attitude of the rocket was such that the angle between the background magnetic field and the boom carrying the Langmuir probe was smallest.

It is difficult to say how much of this band structure is already present in the data before 180 sec. At least the signal just above the LHR frequency can occasionally be seen as well as the signal near the hydrogen cyclotron frequency. Also the presence of the band structure according to the hydrogen cyclotron harmonics in the electric field data is uncertain. This can be due to much lower signal to noise ratio in the E-field data than in the $\delta n/n$ data above the altitude of 300 km. Here again the highest of the bands can often be seen but the signal near the hydrogen cyclotron frequency is always absent

Figure 5 shows the electric field data from the same time period as figure 4. Here the basic characteristics of the electric field data are seen: no signal near the hydrogen cyclotron frequency, the highest frequency band of the LHR noise is present, additional broad band noise above the LHR frequency. From the lower parts of the LHR noise

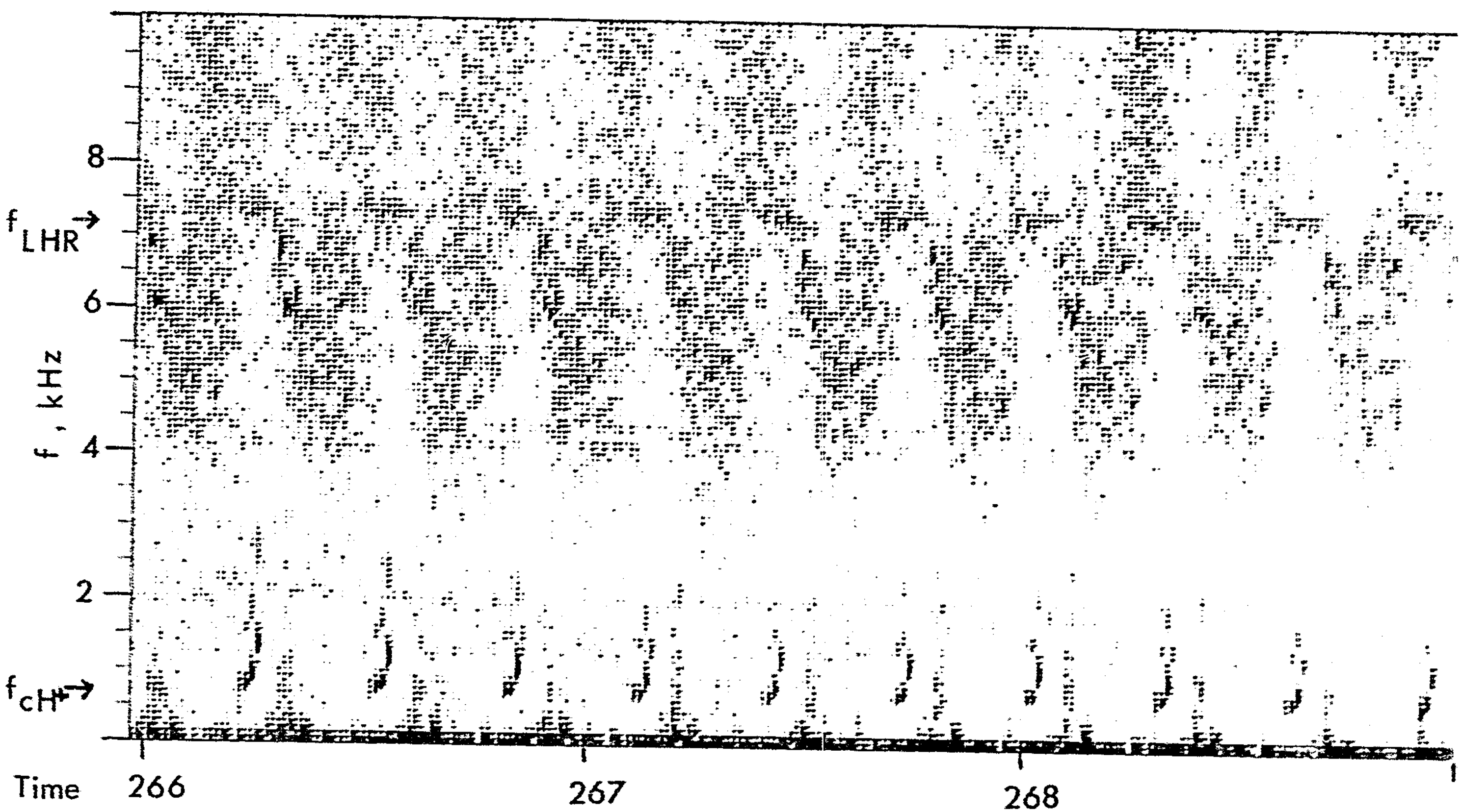

Figure 4

Sonogram of δn/n data with a better temporal resolution (each spectral line corresponds 0.0128 sec.).

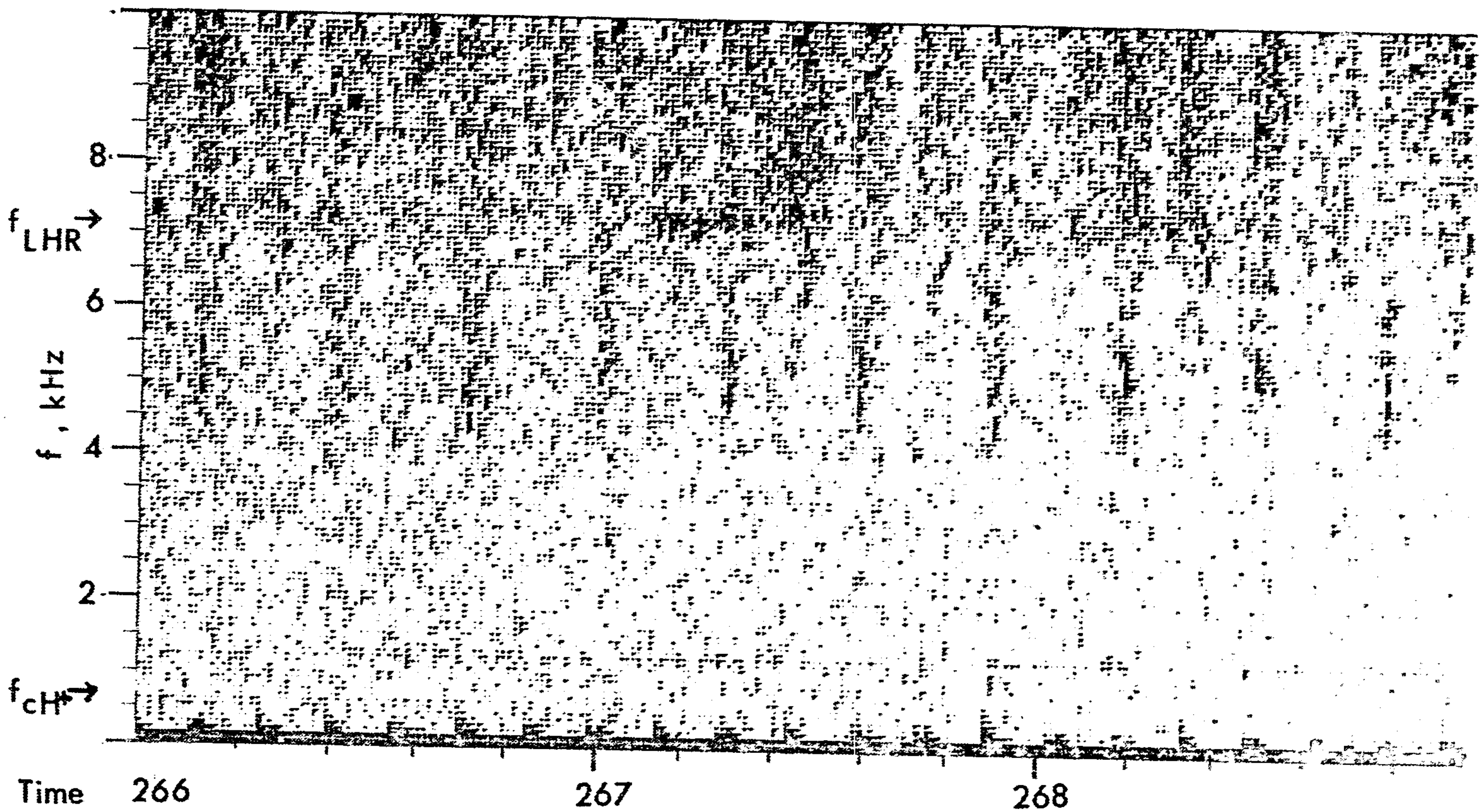

Figure 5

Sonogram of electric field data from the same time period as fig. 4.

only a short signal is seen once per the spin of the rocket. Since the double probe antenna is symmetric, we would expect emissions twice per spin but only a very weak signal can sometimes be seen after an additional revolution of 180 degrees. The stronger signal appears approximately 90 degrees phase shifted after the corresponding signal in $\delta n/n$ data. The electric field antenna in question was perpendicular to the $\delta n/n$ antenna, thus this suggests that the measured phenomenon is very localized in relation to the rocket. However, we know of no asymmetries which could explain the observation of once per spin electric field signals.

During the downleg part of the flight the $\delta n/n$ registration is less noisy but the LHR noise is seen almost all the time. After 545 sec (below 180 km) somewhat similar broader bands are seen as in the beginning of the flight. Now we are able to follow these lower into the ionosphere than during the upleg part and the frequency becomes lower and consistent with the LHR frequency when the ion composition changes to include heavier ions.

The fluctuations in the magnetic field were also measured but due to the small signal to noise ratio it is impossible to make any conclusions about the LHR noise in the magnetic component.

4. Discussion and conclusions

The LHR noise presented above reaches below the LHR frequency and sometimes has a harmonic band structure. It also seems to be mainly electrostatic because we see it clearly in the $\delta n/n$ measurement. At the moment we are not able to say anything of the E/B ratio of the wave field, so it is impossible to be sure how much of the noise could be electromagnetic. The theory presented by Hamelin and Beghin (1976) predicts harmonic structure on both sides of

the LHR frequency and also that the noise should be electrostatic. Thus our measurements seem to be consistent with that theory.

A comparision with the data published by Kamada et al. (1981) suggest that we have measured the same phenomenon as they. However, they do not seem to have had a direct electrostatic measurement and they try to understand their data as electromagnetic noise (hiss) although they report not finding any magnetic component.

The fact that we do not see any cut-off at local LHR frequency should not be interpreted as a failure in theory. We have to keep in mind that the concept of the lower hybrid resonance is derived within the framework of the cold plasma theory. Considering the wave normal surfaces with the aid of the CMA diagrams (Stix, 1962) it is easy to see that LHR is the transition line where the topology of the wave normal surfaces change and it is this change which is seen as the lo -frequency cut-off for the lower hybrid (LH) waves. r the waves very near the resonance the phase velocity becomes very small and the cold approximation naturally breaks down. Furthermore if there are some harmonic phenomena (like the ion Bernstein modes) involved the only correct theoretical treatment is the hot microscopic theory.

We think the most important problem here is to identify the source of free energy and the generation mechanism of this noise. The flight took place during a rather strong auroral activity (as did also S-310JA-6) and it would be very tempting to suggest the noise to be due to some wave-particle interaction between precipitating electrons and the ionospheric plasma. As a matter of fact, the noise was stronger during the upleg part of the flight when there were also more energetic electrons. The correlation is not very good, however. A much better correlation can be

seen between the noise and the spin of the rocket. Furthermore when we analysed the banded structure more in detail (fig.4) we noted that even the different bands appear in different spin phases. Frequently a specific emission occured during only a small rotation angle of the spin cycle. For example, the emissions near the fundamental of the hydrogen cyclotron frequency were present only 70 degrees of arc. Since the $\delta n/n$ sensor measures a scalar (density) it is difficult to understand the time history of the emissions unless they are localized in specific regions, perhaps both in space and time, whose positions are defined with respect to the rocket. The electric field measurements support this hypothesis. Some features of the $\delta n/n$ measurements, such as the emissions near the hydrogen cyclotron frequency are not found in the electric field measurements while other features near the LHR frequency do exist in the electric field measurements. Since the boom length of the $\delta n/n$ sensor was 50 cm compared to two antennae of 210 cm for the electric field, the emissions appear to be localized in radius as well as spin angle. Thus we suspect that the noise was created by the rocket itself though we do not know how. This point of view is supported by the recent Siple rockets where similar noise was detected also without any auroral activity.

If we accept that the emissions are locally produced, then a local source of free energy must be determined. The only available source of free energy is the rocket velocity ($\approx$1 km/s) compared to the ion thermal velocity ($\approx$1.5 km/s). The rocket motion will produce an upstream beam of ions which have reflected off its surface, while downstream a lopsided distribution function will occur where the rocket has swept away ions whose velocity vector is antiparallel to the rocket. Since the electron thermal velocity is of the order of 200 km/s it does not seem likely the electron distribution function will be seriously affected.

The recent works by Cattell and Hudson (1982), and Kintner and Kelley (1982) also indicate that the problem of finding the free energy source should be studied further by examining carefully the possible effects of the rocket on the local ion distribution and solving the linear dispersion relation for the appropriate distribution functions. However, this approach presents two problems. First, there are no measurements of the disturbed distribution functions and any estimates would naturally be uncertain. Second, there may be important nonlinear aspects of the problem. For example, in the Ba-GEOS data the simultaneous occurrences of the possible LH and EIC waves suggest the possibility that the lower frequency bands in the LHR noise could be a product of a wave - wave interaction between the LH and EIC waves. In this case the process would be nonlinear and the linear treatment would not be complete.

The results presented here do point to a specific conclusion. That is caution must be exercized in interpreting plasma wave data. An emission at a natural frequency of the plasma does not imply that the emission is natural. The ratio of probe length to vehicle dimension (≅1 for sounding rockets) may be an important parameter in determining whether the waves are measurable. Hence, satellites where probe lengths often are much larger than the spacecraft dimensions may escape contamination by the phenomena presented here. However, wave experiments on the space shuttle have a probe length to vehicle dimension ratio which is smaller than in sounding rockets and, in fact, the plasma diagnostics package on the shuttle has observed locally produced, electrostatic waves near the lower hybrid frequency (S. Shawhan, private communication).

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